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Management Strategies for Charcoal Rot of Sesame: A Review

Preeti Vashisht [a++*], N. K. Yadav [b#], Rahul Kumar [a], Parul Jangra [a] and Jyoti Indora [a†]

[a] CCSHAU, Hisar, Haryana, India.
[b] Regional Research Station, Bawal, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author PV designed the study and wrote the manuscript, all the co-authors helped in finding the literature cited and all the authors have read the manuscript properly. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Sesame (*Sesamum indicum* L.*)* commonly known as *til* is one of the important oilseed crop having good nutritional, biomedical and religious value. It is also called as "Queen of oilseeds" and among the oilseed crops , sesame ranks first for its higher oil content with a dietary energy of 6335kcal/kg in seeds. The crop is attacked by several pathogens causing serious diseases and act as major damaging factor to sesame crop cultivated in the whole world with severe losses of 7million tones yearly. The important diseases of sesame include charcoal rot (*Macrophomina phaseolina*, Fusarium wilt (*Fusarium oxysporum*), Phytophthora blight (*Phytophthora parasitica*) and phyllody (phytoplasma). Charcoal rot is caused by *Macrophomina phaseolina* has been a major threat to the successful cultivation of sesame in Haryana which causes about 5-100% loss. The pathogen being facultative in nature survives as microsclerotia in soil and infested plant debris that serve as the primary source of inoculum and have been found to persist within the soil up to three years.The

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[++] Ph.D. Scholar;
[#] Assistant Scientist;
[†] M.Sc. Scholar;
**Corresponding author: E-mail: dhimanpreeti45@gmail.com;*

pathogen not only persists in soil as saprophyte associated with other soil microorganisms but also transmitted through seed. Hence, it requires different management approaches to overcome this menace. So, keeping in view the present scenario ecofriendly management must be done by the use of botanicals and bio agents.

Keywords: Sesame; charcoal rot; pathogen; disease; Macrophomina phaseolina.

1. INTRODUCTION

Charcoal rot caused by *Macrophomina phaseolina* (Tassi) Goid by is one of the most important diseases of sesame in Haryana. The pathogen is widely distributed and highly destructive right from the sowing to all stages of crop growth [1]. The disease takes a heavy toll resulting in root and stems rot, loss of plant population and subsequently yield loss. Scanty systematic information is available on eco-friendly management of this disease in Haryana, hence the present review have a direct or indirect bearing on the investigation carried out in the studies.

2. THE HOST

Sesame (*Sesamum indicum* L.) is an important annual oilseed crop belongs to the family Pedaliaceae. Sesame is grown mainly for seed purpose which has a good quality food, nutrition, bio-medicine, health care and religious value. Due to potent medicinal properties in leaves, oil and seeds of sesame are used to cure hemorrhoids, ulcers, cough, asthma and many other diseases. Sesame is used in various industries like pharmaceutical industry for making pharmaceutical products, cosmetics industry for making soaps, sunscreen cream and insecticide industries for enhancing efficacy of pyrethrin and make it more effective to combat against insects. Sesame is a traditional and high valued crop due to its nutritional and medicinal properties. Despite of high nutritive, economic value and large acreage; production and productivity of crop is low in state as well as in the country.

3. OCCURRENCE AND ECONOMIC IMPORTANCE OF DISEASE

Charcoal rot is one of the most common, widely distributed and destructive root and stem rot disease. In India, charcoal rot of sesame incited by *Macrophomina phaseolina* (Tassi) Goidanich was first reported from Uttar Pradesh [2]. Jain and Kulkarni reported this disease from Jabalpur and Gwalior divisions of Madhya Pradesh. Now it is widely distributed in all sesame growing areas of Uttar Pradesh, Madhya Pradesh, Gujarat, Maharashtra, Haryana, Punjab, Bihar, West Bengal, Orissa, Tamilnadu, Karnataka and Kerala. Generally, pathogen of charcoal rot appears to be non-specific in nature and causes diseases in sesame, maize, sorghum, soybean, sunflower and other economically important crops and responsible for huge losses every year in India [3,4]. Generally, about 25% yield losses by charcoal rot in United States, Uruguay, Spain and Soviet Union has been observed but under favourable weather conditions for the growth and development of pathogen, total crop failure in specific areas have also been recorded [5]. Murugesan et al*.,* reported that 1.8kg/ha sesame yield losses at every one per cent increase in charcoal rot disease intensity [6]. The disease was reported from North and South America, Asia, Africa and Europe but more prevalent in subtropical and tropical countries with a semi-arid climate. Yu and Park found that *M. phaseolina* causes severe reduction in seed germination and seedling stand [7]. Vyas observed charcoal rot is very serious and destructive disease in sesame growing areas and causes 5-100% yield losses [8]. Hoes observed that this disease is a serious threat for crops especially in arid regions of the world [9]. Maiti et al*.,* estimated yield loss of 57% at 40% of disease incidence [10]. Dinakaran and Mohammed found charcoal rot caused by *M. phaseolina* is the most devastating disease among diseases of sesame [1]. Chattopadhyay and Kalpana reported about 50% incidence of charcoal rot resulting in heavy yield losses in India [11]. Deepthi et al., estimated yield losses in sesame due to *M. phaseolina* at capsule formation stage and observed plant protected with fungicides had more number of capsules per plant and test weight of healthy than infected capsule [12]. Min and Toyoto reported that the incidence of sesame charcoal rot was 10-30% which causes 10-75% yield losses in Myanmar [13].

4. THE PATHOGEN

Macrophomina phaseolina (Tassi) Goidanich is destructive, omnipresent and non - specific pathogen with vast host range. Tassi first identified the pycnidial stage of the fungus as *M.*

phaseolina [14]. Pathogen is best known as the cause of a disease aptly called "charcoal rot". Taubenhaus discovered sclerotial stage *i.e*. *Sclerotium bataticola* (Taub) and identified the fungus as causal agent for charcoal rot of sweet potato in USA [15]. Petrak established genus *Macrophomina* which was parasitic on sesame [16]. Charcoal rot fungus is referred as *M. phaseolina* due to sclerotial-bearing mycelial stage and causes characteristic root rot disease. In India, Butler identified a similar sclerotial-bearing fungus and compared with isolates of Taubenhaus and named as *Rhizoctonia bataticola* (Taub.) Butler; subsequently it was transferred to *Macrophomina* by Goidanich [16,17]. *M. phaseolina* (Tassi) Goidanich belongs to phylum *Ascomycota*, class *Dothideomycetes*, order *Botryosphaeriales*, family *Botryosphaeriaceae*, genus *Macrophomina* and species *phaseolina*. The hyphae of pathogen are branched at right angle with constriction and a septum just after constriction [18]. Chaudhary et al*.,* reported that the pathogen continuously changes its nature and rapidly resistant cultivars become susceptible [19]. The absence of known teleomorph has stalled its taxonomy for many years [20]. The severity of disease is directly related to the presence of viable sclerotia in the soil [21]. Sapru and Mahajan, reported that it is a facultative parasite in nature [22]. It is both externally and internally seed borne pathogen. It is considered to be seed, soil and stubble borne in nature which can survive for more than ten months under dry soil conditions in the form of sclerotia. The hyphae are septate and filliform. Initially hypha is hyaline afterwards becoming grey to black and producing jet black oval to round microsclerotia of size 80-90µm in diameter [23]. Akhtar et al*.,* proved the necrotrophic behavior of pathogen in sesame and found seed infection efficiency of *M. phaseolina* was 100% with significant reduction in seed index [24]. Chowdhury et al., reported that infection stages of charcoal rot fungus *M. phaseolina* in sesame revealed a transition phase from biotrophy via BNS (biotrophy-to-necrotrophy switch) to necrotrophy [25].

5. DISEASE SYMPTOMS

The most common symptom of charcoal rot is the sudden wilting of plants from top to downwards throughout crop growth period. Irregular and deep necrotic lesions tend toward hypocotyls and root surfaces were found in soybean [26]. Lesions coalesce to form larger patches on branches or other plant parts, leads to premature senescence and death of plant [27]. Toxins production and sclerotia formation by pathogen in xylem play an important role in the dehydration of adult plant leads to wilting. *M. phaseolina* infected plants dry up and roots are decayed in a shredded appearance [28]. Seedling blight, root rot and stem rot are the salient symptoms of charcoal rot of soybean [29]. Irregular and deep necrotic lesions in hypocotyls and root surfaces were observed in chickpea and sorghum [30,31]. Colonization of epidermal and cortical cells is followed by colonization of vascular cambium and phloem cells in chickpea and maize]32,33]. Microsclerotia germinate and produce hypha which penetrate the epidermal cells and grows intercellular. This infection leads to cellular collapse, epidermal and cortical cells necrosis in the roots and hypocotyls of common bean [34]. Fungal sclerotia overwinter on weeds and attack plant roots and causing decaying of fibrous roots and blackening of the stems [35]. The fungus interrupts the function of xylem vessels causing wilting and premature death of plant [36]. *M. phaseolina* is worldwide distributed and infects different parts of plant and causes root rot, stem rot and seedling blight [37]. Pathogen mainly attacks at basal region of the plant and causes lesions on roots, stems, pods and seeds [38]. The plant undergoes several morphological changes after attack of the pathogen including irregular lesions having grey centers with dark brown borders, death of nodes and finally wilting [39].

6. EVALUATION OF PHYTOEXTRACTS/BOTANICALS

Management of charcoal rot pathogen is very difficult due to its long-term survival and wide host range. Minimum incidence of charcoal rot (3.3%) was found by the treatment of rhubarb followed by neem (6.7%) as compared to control (23.3%) under screen house conditions [35]. Tandel et al*.,* tried phytoextracts of eleven plant species against *M. phaseolina* of green gram and revealed that the onion bulb extract produced maximum inhibition of mycelia growth of root rot fungus [40]. Kumar et al*.,* studied the integrated management of Jatropha root rot caused by *Rhizoctonia bataticola* by using different phytoextracts and revealed that neem extract produced the maximum growth inhibition of the pathogen at 20% concentration by 55.6% [41]. Murugapriya et al*.,* tested some botanicals against *M. phaseolina* and observed that growth was inhibited with extracts of *Allium* spp [42]. Management of charcoal rot pathogen is very difficult due to its long-term survival and wide host range. It persists in the soil as saprophytes, associated with other soil organisms and transmitted from seed. Dhingani et al*.,* tested the bio-efficacy of phytoextracts of thirteen plant species against *Macrophomina phaseolina* causing root rot disease of chickpea under *in vitro* condition by using poison food technique and observed that maximum per cent inhibition was done by *Allium sativum* (73%) followed by *Curcuma longa* , 63.98 per cent inhibition [43]. Hussain et al*.,* evaluated the efficacy of different plant extracts against the pathogen *Macrophomina phaseolina* causing charcoal rot of sunflower under *in vitro* conditions and revealed that *Allium sativum* produced maximum growth inhibition followed by *Parthenium hysterophorus* and *Cassia fistula* and minimum growth inhibition was produced by *Dalbergia sissoo* [44]. Tabassum et al*.,* tried phytoextracts of different plant species and revealed that the seeds treated with extract of ginger rhizome showed maximum per cent inhibition [45]. Meena et al*.,* tested the bio-efficacy of various plant extracts against *M. phaseolina* at different concentrations (10%, 15%, 20%) and revealed that rhizome extract of *Zingiber officinale* produced maximum growth inhibition (74.59%) of the pathogen [46]. Iqbal et al*.,* tested the antifungal potential of twenty antagonistic plants against the pathogen *M. phaseolina* causing charcoal rot in mungbean and found that all the test plants inhibited the growth of *M. phaseolina* significantly to varying levels [47]. The maximum inhibition was observed with *Carum copticum* (83.5%), *Azadirachta indica* (76.1%) and *Nigella sativa* (70.4%) at 10% concentration. The powders of *Olea europaea*, *Cassia angustifolia*, *Ocimum americanum* and *Lawsonia inermis* caused more than 50% reductions in the growth of the fungus. Savaliya et al*.,* evaluated the efficacy of phytoextracts of nine plant species under *in vitro* conditions using poison food technique against *M. phaseolina* and revealed that maximum growth of mycelium was inhibited by *Allium sativum* [48]. Akanmu et al*.,* tested the inhibitory potential of four combined botanicals (*Ficus asperifolia*, *Momordica charantia*, *Anacardium occidentals*, *Psidium guajava*) on mycelial growth of *M. phaseolina* of cowpea and revealed that *Momordica charantia* was most effective in botanicals treatment alone and combined treatment of *Ficus asperifolia*, *Momordica charantia* and *Anacardium occidentals* was found most significant [49]. Gojiya et al*.,*evaluated the different phytoextracts against *M. phaseolina* causing root rot of greengram and revealed that the extract of garlic cloves (*Allium sativum*) was proved excellent with maximum inhibiting (65.68%) mycelial growth of the pathogen [50]. Khamari et al*.,* tried phytoextracts of thirty plant species against the pathogen causing root rot of sesame using water and methanol as solvents *in vitro* and revealed that the garlic registered maximum per cent mycelial inhibition followed by onion at all concentrations in methanol as well as in aqueous extract [51]. Lakhran and Ahir tested the phytoextracts agsinst the pathogen causing root rot in chickpea and observed that the garlic extract was found most effective in reducing root rot incidence followed by neem leaf extract [52]. Khaire et al*.,* evaluated the efficacy of different phytoextracts of different plant species reduced mycelial growth of pathogen causing charcoal rot [53]. Gwande et al*.,* tested bio-efficacy of botanicals against *Macrophomina phaseolina* causing dry root rot of safflower under *in vitro* conditions and observed that the maximum inhibition was done by *Allium sativum* (83.57%) followed by *Allium cepa* (72.09%) and *Vitex negundo* (65.85%) [54]. Thombre and Kohire evaluated the bioefficacy of different botanicals against *M. phaseolina* under *in vitro* conditions and observed that all the botanicals were found effective in reducing per cent mycelial growth of *M. phaseolina* [55].

7. EVALUATION OF ANTAGONISTS

7.1 *In vitro* Evaluation

Raguchander et al*.,* tested the antagonistic activity of biocontrol agent isolates by using talc as a carrier against root rot of mungbean and revealed that maximum growth inhibition was produced by *Trichoderma viride*-III isolate [56]. Dinakaran and Marimuthu studied the antagonistic efficacy of bio- agents against *Rhizoctonia bataticola* and observed that *Trichoderma viride* exhibited the highest *in vitro* inhibition of mycelial growth (54.4%) and sclerotial germination (75.8%) [57]. Bashar and Khatum observed that *Trichoderma hamatum* and *Trichoderma viride* were most potent antagonists against *Rhizoctonia bataticola* [58]. Gupta et al*.,* evaluated the antagonistic efficacy of *Pseudomonas* strain biocontrol agent and observed that this strain showed a strong antagonistic effect against *M. phaseolina* [59].

Salunke et al*.,* tested the efficacy of bio agents against *Rhizoctonia bataticola* and observed that *Trichoderma viride* was found most effective against the pathogen followed by *T. harzianum* and *Pseudomonas fluorescens* [60]. Rani et al*.,* reported the inhibitory action of bioagents viz., *Trichoderma viride*, *T. harzianum* and *Bacillus subtilis* against *Macrophomina phaseolina* [61]. Rajput et al*.,* evaluated the efficacy of biological control agents against *Rhizoctonia bataticola* under in vitro conditions and revealed that *Trichoderma harzianum* caused maximum radial growth inhibition (69.62%) of pathogen [62]. Jaiman and Jain tested the antagonistic activity of five bio-agents viz., *Trichoderma viride*, *T. harzianum*, *Pseudomonas fluorescens*, *Bacillus subtilis* and *Gliocladium virens* against the pathogen and observed that maximum inhibition (69.62%) was showed by *T. viride* followed by *T. harzianum* under *in-vitro* conditions [63]. Kumar et al*.,* studied the integrated management of root rot disease of Jatropha caused by *Rhizoctonia bataticola* by using different biocontrol agents and revealed that mximum inhibition was produced by *Trichoderma harzianum* [41]. Sreedevi et al*.,* evaluated the efficacy of five species of *Trichoderma* for biocontrol of *Macrophomina* causing root rot of groundnut under *in vitro* conditions by dual culture and bioassays methods and they revealed that among the five isolates *T. harzianum* (T3) and *T. viride* (T1) had maximum antifungal activity against the pathogen. *Trichoderma viride* and *T. harzianum* reduced the mycelial growth by 61.1% and 64.4% respectively [64].

Kumari et al*.,* studied the integrated management of root rot of mungbean incited by *M. phaseolina* by using biocontrol agents and reported that among the tested biocontrol agents *Trichoderma harzianum* was found most effective against the pathogen under *in vitro* conditions followed by *T. viride* and *T. polysporum*, *Pseudomonas fluorescens* was found least effective in reducing root rot incidence [65]. Manjunatha et al*.,* evaluated the activity of isolates of bio-control agents against *Macrophomina phaseolina* caused dry root rot of chickpea and revealed that *T. viride* and *T. harzianum* were effective against the pathogen , as Tv-R isolate of *T. viride* was found to be most effective. Pf-4 isolate of *Pseudomonas fluorescens* was also found to be more effective than the other isolates [66]. Arshad et al*.,* evaluated the antagonistic efficacy of seven species of *Trichoderma* named as *T. pseudokoningii*, *T. harzianum*, *T. reesi*, *T. koningii*, *T.hanatus*, *T. viride*, *T. aureoviride* against the pathogen and observed that maximum per cent inhibition was done by *T. harzianum* and overall reduction in mycelium growth was 45-65%. *Trichoderma harzianum* was found to be most effective against the pathogen followed by *T. aureoviride* and *T. hanatum* [67]. Tetali et al*.,* (2015) studied the management of disease by using biocontrol agents and revealed that the best antagonistic action was shown by *Trichoderma viride* [68]. Meena and Pandey tested the antagonistic property of bio-agents viz., *Trichoderma viride*, *T. harzianum*, *T. virens* and *Pseudomonas fluorescens* against *M. phaseolina* causing root rot of mungbean and observed that maximum inhibition was shown by *T. viride* [69]. Satpathi and Gohel tested the antagonistic potential of eight biocontrol agents against *M. phaseolina* causing root rot of sesame and revealed the *Trichoderma atroviride* showed strong antagonistic effect against the pathogen with highest growth inhibition (60.00%) [70].

Thombre and Kohire evaluated the bioefficacy of bioagents against *M. phaseolina* under *in vitro* conditions and observed that all the bioagents exhibited fungistatic activity against *M. phaseolina* and inhibited mycelial growth of pathogen [55]. Brahmbhatt (2018) studied the management or root and collar rot of okra caused by *Macrophomina phaseolina* by using different bio agents and observed that *Trichoderma viride* was the most effective with highest growth inhibition (73.06%) followed by *Trichoderma harzianum* (68.89%) [71].

8. EFFECT OF SEED TREATMENT WITH ANTAGONISTS

Gupta et al*.,* evaluated the antagonistic efficacy of *Pseudomonas* strain biocontrol agent and observed that this strain showed a strong antagonistic effect against *M. phaseolina* and seed treatment with this strain increased the seed germination besides enhancing early seedling growth [72]. Indra and Gayathri tested the efficacy of biocontrol agents in different carriers against root rot of blackgram caused by *M. phaseolina* and observed that the disease incidence was significantly reduced by 50% when treated with *Trichoderma* spp. alone or in combination with biofertilizer. The root length, shoot length, grain yield and nodulation significantly increased with the *T. harzianum* + *Rhizobium* treated seeds (22.26 cm), *T. viride* + *Rhizobium* treated seeds (36.93 cm), *T. harzianum* (gypsum formulation) + *Rhizobium* (661.66 kg/ha) and *T. viride* + *Rhizobium* (22.33 nodules/plant) respectively [73]. Ramesh and

Korikanthimath studied the management of root rot of groundnut caused by *M. phaseolina* by using bio control agents (*Tricoderma viride* and *Pseudomonas fluorescens*) and observed that seed treatment with biocontrol agents increased the germination percentage 11-23 % and 54-82% , and reduced disease incidence significantly 40-58 and 55-77 % [74]. Kumari et al*.,* studied the integrated management of root rot of mungbean incited by *Macrophomina phaseolina* by using biocontrol agents and reported that among the tested biocontrol agents *Trichoderma harzianum* was found most effective against the pathogen in pots conditions followed by *T. viride* and *T. polysporum*, *Pseudomonas fluorescens* was found least effective in reducing root rot incidence [65].

Iqbal et al*.,* tested the antifungal potential of twenty antagonistic plants against the pathogen *M. phaseolina* causing charcoal rot in mungbean and found that the maximum seedling emergence was observed when the seeds were treated with *C. copticum* (83.3%) followed by *A. indica* (80.0%) at 10% [47]. Khalili et al*.,* evaluated the antagonistic potential of *Trichoderma* isolates (T_{12},T_2,T_{10}) against *M. phaseolina* causing charcoal rot of soybean and observed that maximum growth inhibition was done by T_{12} isolate by (72.31%) and production assays by 63.36%. T_{12} isolate was also found most effective under *in vivo* conditions by seed treatment [39]. Adhikary et al*.* [75] studied the integrated management of root rot of sesame using biocontrol agents and reported that disease incidence can be checked by seed treatment with *T. viride* + *P. fluorescens* @ 10g/kg + soil application of *P. fluorescens* @ 2.5kg/ha + *T.viride* @ 2.5kg/ha enriched in 100 kg of FYM + neem cake @ 250kg/ha at sowing.

9. EFFECT OF SOIL APPLICATION

Khalili et al*.,* evaluated the antagonistic potential of *Trichoderma* isolates (T_{12},T_2,T_{10}) against *M. phaseolina* causing charcoal rot of soybean and observed that maximum growth inhibition was done by T_{12} isolate by (72.31%) and production assays by 63.36%. T_{12} isolate was also found most effective under *in vivo* conditions by soil inoculation [39]. Gupta et al*.,* studied the effective integrated management practice of charcoal rot in sesame by soil application of *T. viride* @ 2.5kg/hac [76]. Dhawan et al*.,* evaluated the effect of different biocontrol agents against dry root rot of clusterbean caused by *Rhizoctonia bataticola* and observed that soil application with *T. viride* @ 10g/kg seed was found most effective against the disease [77].

10. EFFECT OF VOLATILE AND NON-VOLATILE COMPOUNDS OF BIO AGENTS

Dinakaran and Marimuthu tested the antifungal activity of nine mutants of *T. viride* against *M. phaseolina* and revealed that cell free culture filtrate of mutant M1 showed the highest *in vitro* inhibition of mycelial growth (54.4%) and sclerotial germination (75.8%)of M. *phaseolina* followed by M3. The mutants M3 and M8 produced maximum volatiles *In vitro* [57]. Sreedevi et al*.,* evaluated the efficacy of different isolates of bio-control agents against *M. phaseolina* causing root rot of groundnut and revealed that among all the isolates *T. harzianum* (T3) and *T. viride* (T1) showed best results in mycelial inhibition. The inhibition varied depending on the *Trichoderma* sp. Producing metabolites, *T. viride* inhibited fungal growth up to 69% and *T. harzianum* upto 79.7% innon-volatile and 47%, 64.7% in volatile metabolites, respectively [64].

11. CONCLUSION

The pathogen not only persists in soil as saprophyte associated with other soil microorganisms but also transmitted through seed. Hence, it requires different management approaches to overcome this menace. Moreover, the control of plant diseases using pesticides raises serious concerns about food and environmental safety and pesticide resistance, which have dictated the need for alternative disease management techniques. Charcoal rot disease in sesame used to appear every year in patches at farmers field at all growth stages in Haryana and usually go unnoticed and causes full amount loss to the crop at a time as the control of disease is not economical and feasible. The disease is inherited by minor genes, hence sources of resistance are not available to ulitilize in vertical resistance breeding programs. Moreover, the use of expensive and excessive pesticides that causes environmental pollution has become concern to public awareness for health hazard to all useful organisms including humans and animals. Keeping in view the importance of the disease in recent years in Haryana due to build up of high inoculum in soil and to avoid soil pollution through chemicals it has become necessary to test botanicals and bio-agents for their effectiveness against this mince.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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